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<b>(21) International Application Number:</b> PCT/US99/26276 <b>(22) International Filing Date:</b> 4 November 1999 (04.11.99)  <b>(30) Priority Data:</b> 09/187,656      6 November 1998 (06.11.98)      US  <b>(71) Applicant:</b> ALLIEDSIGNAL INC. [US/US]; 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962-2245 (US).  <b>(72) Inventors:</b> DECRISTOFARO, Nicholas, John; 33 Lincoln Avenue, Chatham, NJ 07928 (US). STAMATIS, Peter, Joseph; 107 Washington Avenue, Morristown, NJ 07960 (US).  <b>(74) Agents:</b> CRISS, Roger, H. et al.; AlliedSignal Inc., Law Dept.(Olinger, A.), 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962-2245 (US).		<b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>Without international search report and to be republished upon receipt of that report.</i>
<b>(54) Title:</b> BULK AMORPHOUS METAL MAGNETIC COMPONENTS FOR ELECTRIC MOTORS  <b>(57) Abstract</b> <p>A high efficiency electric motor has a generally polyhedrally shaped bulk amorphous metal magnetic component in which a plurality of layers of amorphous metal strips are laminated together to form a generally three-dimensional part having the shape of a polyhedron. The bulk amorphous metal magnetic component may include an arcuate surface, and preferably includes two arcuate surfaces that are disposed opposite to each other. The magnetic component is operable at frequencies ranging from between approximately 60 Hz and 20,000 Hz and exhibits (i) a core-loss of less than or approximately equal to 1 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 60 Hz and at a flux density of approximately 1.4 Tesla (T); (ii) a core-loss of less than or approximately equal to 20 watts-per-kilogram of amorphous metal material when operated at a frequency of approximately 1000 Hz and at a flux density of approximately 1.4 T and (iii) a core-loss of less than or approximately equal to 70 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 20,000 Hz and at a flux density of approximately 0.30T. Performance characteristics of the bulk amorphous metal magnetic component of the present invention are significantly better when compared to silicon-steel components operated over the same frequency range.</p>		

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# **BULK AMORPHOUS METAL MAGNETIC COMPONENTS FOR ELECTRIC MOTORS**

## **BACKGROUND OF THE INVENTION**

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### **1. Field Of The Invention**

This invention relates to amorphous metal magnetic components, and more particularly, to a high efficiency electric motor having a generally polyhedrally shaped bulk amorphous metal magnetic component.

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### **2. Description Of The Prior Art**

An electric motor typically contains magnetic components made from a plurality of stacked laminations of non-oriented electrical steel. In variable reluctance motors and eddy current motors, the stators are made from stacked laminations. Both the stator and the rotor are made from stacked laminations in squirrel cage motors, reluctance synchronous motors and switched reluctance motors. Each lamination is typically formed by stamping, punching or cutting the mechanically soft, non-oriented electrical steel into the desired shape. The formed laminations are then stacked and bound to form the rotor or stator.

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Although amorphous metals offer superior magnetic performance when compared to non-oriented electrical steels, they have long been considered unsuitable for use in bulk magnetic components such as the rotors and stators of electric motors due to certain physical properties and the corresponding fabricating limitations. For example, amorphous metals are thinner and harder than non-

oriented steel and consequently cause fabrication tools and dies to wear more rapidly. The resulting increase in the tooling and manufacturing costs makes fabricating bulk amorphous metal magnetic components using such techniques commercially impractical. The thinness of amorphous metals also translates into an increased number of laminations in the assembled components, further increasing the total cost of an amorphous metal rotor or stator magnet assembly.

Amorphous metal is typically supplied in a thin continuous ribbon having a uniform ribbon width. However, amorphous metal is a very hard material, making it very difficult to cut or form easily, and once annealed to achieve peak magnetic properties, becomes very brittle. This makes it difficult and expensive to use conventional approaches to construct a bulk amorphous metal magnetic component. The brittleness of amorphous metal may also cause concern for the durability of the bulk magnetic component in an application such as an electric motor.

Another problem with bulk amorphous metal magnetic components is that the magnetic permeability of amorphous metal material is reduced when it is subjected to physical stresses. This reduced permeability may be considerable depending upon the intensity of the stresses on the amorphous metal material. As a bulk amorphous metal magnetic component is subjected to stresses, the efficiency at which the core directs or focuses magnetic flux is reduced resulting in higher magnetic losses, increased heat production, and reduced power. This stress sensitivity, due to the magnetostrictive nature of the amorphous metal, may be caused by stresses resulting from magnetic and mechanical forces during the operation of the electric motor, mechanical stresses resulting from mechanical

clamping or otherwise fixing the bulk amorphous metal magnetic components in place, or internal stresses caused by the thermal expansion and/or expansion due to magnetic saturation of the amorphous metal material.

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### **SUMMARY OF THE INVENTION**

The present invention provides a bulk amorphous metal magnetic component having the shape of a polyhedron and being comprised of a plurality of layers of amorphous metal strips for use in highly efficient electric motors. Also provided by the present invention is a method for making a bulk amorphous metal magnetic component. The magnetic component is operable at frequencies ranging from about 10 60 Hz to 20,000 Hz and exhibits improved performance characteristics when compared to silicon-steel magnetic components operated over the same frequency range. More specifically, a magnetic component constructed in accordance with the present invention will have (i) a core-loss of less than or approximately equal to 1 15 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 60 Hz and at a flux density of approximately 1.4 Tesla (T); (ii) a core-loss of less than or approximately equal to 20 watts-per-kilogram of amorphous metal material when operated at a frequency of approximately 1000 Hz and at a flux density of approximately 1.4 T, and (iii) a core-loss of less than or 20 approximately equal to 70 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 20,000 Hz and at a flux density of approximately 0.30T.

In a first embodiment of the present invention, a bulk amorphous metal magnetic component comprises a plurality of substantially similarly shaped layers of amorphous metal strips laminated together to form a polyhedrally shaped part.

The present invention also provides a method of constructing a bulk amorphous metal magnetic component. In accordance with a first embodiment of the inventive method, amorphous metal strip material is cut to form a plurality of cut strips having a predetermined length. The cut strips are stacked to form a bar of stacked amorphous metal strip material and annealed. The annealed, stacked bar is impregnated with an epoxy resin and cured. The stacked bar is then cut at predetermined lengths to provide a plurality of polyhedrally shaped magnetic components having a predetermined three-dimensional geometry. The preferred amorphous metal material has a composition defined essentially by the formula  $\text{Fe}_{80}\text{B}_{11}\text{Si}_9$ .

In accordance with a second embodiment of the method of the present invention, an amorphous metal ribbon is wound about a mandrel to form a generally rectangular core having generally radiused corners. The generally rectangular core is then annealed, impregnated with epoxy resin and cured. The short sides of the rectangular core are then cut to form two magnetic components having a predetermined three-dimensional geometry that is the approximate size and shape of said short sides of said generally rectangular core. The radiused corners are removed from the long sides of said generally rectangular core and the long sides of said generally rectangular core are cut to form a plurality of polyhedrally shaped magnetic components having the predetermined three-dimensional geometry. The

preferred amorphous metal material has a composition defined essentially by the formula  $\text{Fe}_{80}\text{B}_{11}\text{Si}_9$ .

The present invention is also directed to a bulk amorphous metal component constructed in accordance with the above-described methods.

5 Construction of bulk amorphous metal magnetic components in accordance with the present invention is especially suited for amorphous metal stators or stator components in highly efficient, variable reluctance motors and eddy current motors. Similarly, bulk amorphous metal components may be used as both the rotor and the stator in squirrel cage motors, reluctance synchronous motors and switched  
10 reluctance motors. The advantages recognized by the present invention include simplified manufacturing and reduced manufacturing time, reduced stresses (i.e., magnetostrictive) encountered during construction of bulk amorphous metal components, and optimized performance of the finished amorphous metal magnetic component.

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#### **BRIEF DESCRIPTION OF THE DRAWINGS**

The invention will be more fully understood and further advantages will become apparent when reference is had to the following detailed description of the preferred embodiments of the invention and the accompanying drawings, wherein  
20 like reference numeral denote similar elements throughout the several views and in which:

**Fig. 1** is a perspective view of a bulk amorphous metal magnetic component in the shape of a three-dimensional rectangle constructed in accordance with the present invention;

**Fig. 2A** is a perspective view of a bulk amorphous metal magnetic component having the shape of a prism and constructed in accordance with the present invention;

**Fig. 2B** is a perspective view of a bulk amorphous metal magnetic component having oppositely disposed arcuate surfaces and constructed in accordance with the present invention;

**Fig. 2C** is a top view of a stator for an electric motor constructed from six prism-shaped components as depicted in **Fig. 2A** and six arcuate components as depicted in **Fig. 2B**;

**Fig. 3A** is a perspective view of a bulk amorphous metal magnetic stator for an electric motor constructed in accordance with the present invention;

**Fig. 3B** is a perspective view of a bulk amorphous metal magnetic rotor for an electric motors constructed in accordance with the present invention;

**Fig. 3C** is a top view of the stator and rotor for an electric motor constructed from the stator of **Fig. 3A** and the rotor of **Fig. 3B**;

**Fig. 4** is a side view of a coil of amorphous metal strip positioned to be cut and stacked in accordance with the present invention;

**Fig. 5** is a perspective view of a bar of amorphous metal strips showing the cut lines to produce a plurality of generally prism-shaped magnetic components in accordance with the present invention;



Fig. 6 is a side view of a coil of amorphous metal strip which is being wound about a mandrel to form a generally rectangular core in accordance with the present invention; and

Fig. 7 is a perspective view of a generally rectangular amorphous metal core showing the cut lines to produce a plurality of generally prism-shaped magnetic components formed in accordance with the present invention.

### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

The present invention is directed to high efficiency motors constructed using bulk amorphous metal components such as, for example stators, rotors, and component parts for stators and rotors. Generally polyhedrally shaped bulk amorphous metal components are constructed in accordance with the present invention having various geometries including, but not limited to, rectangular, square, prism. In addition, any of the previously mentioned geometric shapes may include at least one arcuate surface, and preferably two oppositely disposed arcuate surfaces to form a generally curved or arcuate bulk amorphous metal component. Furthermore, complete stators and rotors may be constructed as a bulk amorphous metal component in accordance with the present invention. Those stators and rotors may have either a unitary construction or they may be formed from a plurality of pieces which collectively form the completed component. Alternatively, a stator and/or rotor may be a composite structure comprised entirely of amorphous metal parts or a combination of amorphous metal parts with other magnetic materials.

Referring now to the drawings in detail, Fig. 1 depicts a generally polyhedrally shaped bulk amorphous metal component 10. As used herein, the term polyhedron refers to a multi-faced or sided solid. This includes, but is not limited to, three-dimensional rectangles, squares, trapezoids, and prisms. In addition, any of the previously mentioned geometric shapes may include at least one, and preferably two, arcuate surfaces or sides that are disposed opposite each other to form a generally arcuately shaped component. The magnetic component 10 depicted in Fig. 1 is comprised of a plurality of substantially similarly shaped layers of amorphous metal strip material 20 that are laminated together and annealed. In a preferred embodiment, a three-dimensional magnetic component 10 constructed in accordance with the present invention and having a flux density of approximately 1.4 Tesla (T) will have (i) a core-loss of less than or approximately equal to 1 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 60 Hz and at a flux density of approximately 1.4 Tesla (T); (ii) a core-loss of less than or approximately equal to 20 watts-per-kilogram of amorphous metal material when operated at a frequency of approximately 1000 Hz and at a flux density of approximately 1.4 T, and (iii) a core-loss of less than or approximately equal to 70 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 20,000 Hz and at a flux density of approximately 0.30T. These performance values apply to the various embodiments of the present invention, regardless of the specific geometry of the bulk amorphous metal component.

The magnetic component 100 depicted in Fig. 2A is generally prism-shaped and preferably includes five (5) sides 110 or surfaces. The pentagonnally-shaped polyhedron component 100 is comprised of a plurality of layers of amorphous metal strip material 20 that are each substantially the same size and shape. The strip material 20 is stacked, laminated together and then annealed.

The magnetic component 200 depicted in Fig. 2B includes at least one, and preferably two oppositely disposed arcuate surfaces 210. The arcuately-shaped component 200 is comprised of a plurality of layers of amorphous metal strip material 20 that are each substantially the same size and shape and that are stacked, laminated together, and annealed.

The bulk amorphous metal magnetic component 300 depicted in Fig. 2C may be used as a stator for a radial gap electric motor and is comprised of six pieces of magnetic component 100 and six pieces of magnetic component 200.

The bulk amorphous metal magnetic component 400 depicted in Fig. 3A is generally circular and includes a plurality of generally rectangular teeth 410 that extend radially inward toward the center of the circular component 400. The component 400 is comprised of a plurality of layers of amorphous metal strip material 20 that are each substantially the same size and shape and that are stacked, laminated together, and then annealed. A bulk amorphous metal component constructed in accordance with the embodiment of Fig. 3A may be used as a stator in a radial air gap electric motor.

The bulk amorphous metal component 500 depicted in Fig. 3B is generally disc-shaped and includes a plurality of generally rectangular teeth 510 that extend

radially outward. The component 500 is comprised of a plurality of layers of amorphous metal strip material 20 that are each substantially the same size and shape and that are stacked, laminated together, and then annealed. A bulk amorphous metal component constructed in accordance with the embodiment of  
5 Fig. 3B may be used as a rotor in a radial air gap electric motor.

Referring next to Fig. 3C, a stator 400 and rotor 500 are constructed as bulk amorphous metal components in accordance with the present invention and used as part of a high efficiency radial air gap electric motor 600.

The present invention also provides a method of constructing a bulk  
10 amorphous metal component. As shown in Fig. 4, a roll 30 of amorphous metal strip material is cut by cutting blades 40 into a plurality of strips 20 having the same shape and size. The strips 20 are stacked to form a bar 50 of stacked amorphous metal strip material. The bar 50 is annealed, impregnated with an epoxy resin and cured. The bar 50 can be cut along the lines 52 depicted in Fig. 5 to  
15 produce a plurality of generally trapezoidally-shaped magnetic components 10. The finished magnetic component 10 may be generally rectangular, trapezoidal, square, or other polyhedral shape. The bar 50 may also be cut to produce three dimensional shapes in the form of pentagonal prisms 11, arc-shaped blocks 12, circular-shaped blocks 13 or disc-shaped blocks 14, as shown in Fig. 2A, 2B, 3A and 3B  
20 respectively.

In a second embodiment of the method of the present invention, shown in Figs. 6 and 7, a bulk amorphous metal magnetic component 10 is formed by winding a single amorphous metal strip 22 or a group of amorphous metal strips 22

around a generally rectangular mandrel 60 to form a generally rectangular wound core 70. The height of the short sides 74 of the core 70 is preferably approximately equal to the desired length of the finished bulk amorphous metal magnetic component 10. The core 70 is annealed, impregnated with an epoxy resin and  
5 cured. Two components 10 may be formed by cutting the short sides 74, leaving the radiused corners 76 on the long sides 78. Additional magnetic components 10 may be formed by removing the radiused corners 76 from the long sides 78, and cutting the long sides 78 at a plurality of locations, indicated by the dashed lines 72. In the example illustrated in Fig. 7, the bulk amorphous metal component 10  
10 has a generally rectangular shape, although other shapes are contemplated by the present invention. The wound core 70 may also be cut to produce three dimensional shapes in the form of pentagonal prisms 11, arc-shaped blocks 12, circular-shaped blocks 13 or disc-shaped blocks 14, as shown in Fig. 2A, 2B, 3A and 3B respectively.

15 Construction in this manner is especially suited for magnetic components such as amorphous metal stator and rotor assemblies in electric motors. Magnetic component manufacturing is simplified and manufacturing time is reduced. Stresses otherwise encountered during the construction of bulk amorphous metal components are minimized. Magnetic performance of the finished components is  
20 optimized.

The bulk amorphous metal magnetic component 10 of the present invention can be manufactured using numerous amorphous metal alloys. Generally stated, the alloys suitable for use in the component 10 construction of the present invention are

defined by the formula:  $M_{70-85} Y_{5-20} Z_{0-20}$ , subscripts in atom percent, where "M" is at least one of Fe, Ni and Co, "Y" is at least one of B, C and P, and "Z" is at least one of Si, Al and Ge; with the proviso that (i) up to ten (10) atom percent of component "M" can be replaced with at least one of the metallic species Ti, V, Cr, Mn, Cu, Zr, Nb, Mo, Ta and W, and (ii) up to ten (10) atom percent of components (Y + Z) can be replaced by at least one of the non-metallic species In, Sn, Sb and Pb. Highest induction values at low cost are achieved for alloys wherein "M" is iron, "Y" is boron and "Z" is silicon. For this reason, amorphous metal strip composed of iron-boron-silicon alloys is preferred. Most preferred is amorphous metal strip having a composition consisting essentially of about 11 atom percent boron and about 9 atom percent silicon, the balance being iron and incidental impurities. This strip is sold by AlliedSignal Inc. under the trade designation METLAS® alloy 2605SA-1.

The bulk amorphous metal magnetic component 10 of the present invention can be cut from bars 50 of stacked amorphous metal strip or from cores 70 of wound amorphous metal strip using numerous cutting technologies. The component 10 may be cut from the bar 50 or core 70 using a cutting blade or wheel. Alternately, the component 10 may be cut by electro-discharge machining or with a water jet.

Bulk amorphous magnetic components will magnetize and demagnetize more efficiently than components made from other iron-base magnetic metals. When used as the rotor or stator in an electric motor, the bulk amorphous metal component will generate less heat than a comparable component made from another

iron-base magnetic metal when the two components are magnetized at identical induction and frequency. The electric motor using the bulk amorphous metal component can therefore be designed to operate 1) at a lower operating temperature; 2) at higher induction to achieve reduced size and weight; or, 3) at higher frequency to achieve reduced size and weight, or to achieve superior motion control, when compared to electric motors using components made from other iron-base magnetic metals.

The following example is presented to provide a more complete understanding of the invention. The specific techniques, conditions, materials, proportions and reported data set forth to illustrate the principles and practice of the invention are exemplary and should not be construed as limiting the scope of the invention.

#### Example 1

##### **Preparation And Electro-Magnetic Testing of an Amorphous Metal Rectangular Prism**

$\text{Fe}_{80}\text{B}_{11}\text{Si}_9$  amorphous metal ribbon, approximately 60 mm wide and 0.022 mm thick, was wrapped around a rectangular mandrel or bobbin having dimensions of approximately 25 mm by 90 mm. Approximately 800 wraps of amorphous metal ribbon were wound around the mandrel or bobbin producing a rectangular core form having inner dimensions of approximately 25 mm by 90 mm and a build thickness of approximately 20 mm. The core/bobbin assembly was annealed in a nitrogen atmosphere. The anneal consisted of: 1) heating the assembly up to 365° C; 2)

holding the temperature at approximately 365° C for approximately 2 hours; and, 3) cooling the assembly to ambient temperature. The rectangular, wound, amorphous metal core was removed from the core/bobbin assembly. The core was vacuum impregnated with an epoxy resin solution. The bobbin was replaced, and the rebuilt, impregnated core/bobbin assembly was cured at 120° C for approximately 4.5 hours. When fully cured, the core was again removed from the core/bobbin assembly. The resulting rectangular, wound, epoxy bonded, amorphous metal core weighed approximately 2100 g.

A rectangular prism 60 mm long by 40 mm wide by 20 mm thick (approximately 800 layers) was cut from the epoxy bonded amorphous metal core with a 1.5 mm thick cutting blade. The cut surfaces of the rectangular prism and the remaining section of the core were etched in a nitric acid/water solution and cleaned in an ammonium hydroxide/water solution.

The remaining section of the core was etched in a nitric acid/water solution and cleaned in an ammonium hydroxide/water solution. The rectangular prism and the remaining section of the core were then reassembled into a full, cut core form. Primary and secondary electrical windings were fixed to the remaining section of the core. The cut core form was electrically tested at 60 Hz, 1,000 Hz, 5,000 Hz and 20,000 Hz and compared to catalogue values for other ferromagnetic materials in similar test configurations [National Arnold Magnetics, 17030 Muskrat Avenue, Adelanto, CA 92301 (1995)]. The results are compiled below in Tables 1, 2, 3 and 4.



TABLE 1

Core Loss @ 60 Hz (W/kg)

Flux Density	Material				
	Amorphous Fe <sub>80</sub> B <sub>11</sub> Si <sub>9</sub> (22 μm)	Crystalline Fe-3%Si (25 μm)	Crystalline Fe-3%Si (50 μm)	Crystalline Fe-3%Si (175 μm)	Crystalline Fe-3%Si (275 μm)
		National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron
0.3 T	0.10	0.2	0.1	0.1	0.06
0.7 T	0.33	0.9	0.5	0.4	0.3
0.8 T		1.2	0.7	0.6	0.4
1.0 T		1.9	1.0	0.8	0.6
1.1 T	0.59				
1.2 T		2.6	1.5	1.1	0.8
1.3 T	0.75				
1.4 T	0.85	3.3	1.9	1.5	1.1

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TABLE 2

Core Loss @ 1,000 Hz (W/kg)

Flux Density	Material				
	Amorphous Fe <sub>80</sub> B <sub>11</sub> Si <sub>9</sub> (22 μm)	Crystalline Fe-3%Si (25 μm)	Crystalline Fe-3%Si (50 μm)	Crystalline Fe-3%Si (175 μm)	Crystalline Fe-3%Si (275 μm)
		National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron
0.3 T	1.92	2.4	2.0	3.4	5.0
0.5 T	4.27	6.6	5.5	8.8	12
0.7 T	6.94	13	9.0	18	24
0.9 T	9.92	20	17	28	41
1.0 T	11.51	24	20	31	46
1.1 T	13.46				
1.2 T	15.77	33	28		
1.3 T	17.53				
1.4 T	19.67	44	35		

TABLE 3

Core Loss @ 5,000 Hz (W/kg)

Flux Density	Material			
	Amorphous Fe <sub>80</sub> B <sub>11</sub> Si <sub>9</sub> (22 μm)	Crystalline Fe-3%Si (25 μm)	Crystalline Fe-3%Si (50 μm)	Crystalline Fe-3%Si (175 μm)
		National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron
0.04 T	0.25	0.33	0.33	1.3
0.06 T	0.52	0.83	0.80	2.5
0.08 T	0.88	1.4	1.7	4.4
0.10 T	1.35	2.2	2.1	6.6
0.20 T	5	8.8	8.6	24
0.30 T	10	18.7	18.7	48

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TABLE 4

Core Loss @ 20,000 Hz (W/kg)

Flux Density	Material			
	Amorphous Fe <sub>80</sub> B <sub>11</sub> Si <sub>9</sub> (22 μm)	Crystalline Fe-3%Si (25 μm)	Crystalline Fe-3%Si (50 μm)	Crystalline Fe-3%Si (175 μm)
		National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron
0.04 T	1.8	2.4	2.8	16
0.06 T	3.7	5.5	7.0	33
0.08 T	6.1	9.9	12	53
0.10 T	9.2	15	20	88
0.20 T	35	57	82	
0.30 T	70	130		

Example 2**Preparation of an Amorphous Metal Trapezoidal Prism**

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Fe<sub>80</sub>B<sub>11</sub>Si<sub>9</sub> amorphous metal ribbon, approximately 48 mm wide and 0.022 mm thick, was cut into lengths of approximately 300 mm. Approximately 3,800 layers of the cut amorphous metal ribbon were stacked to form a bar approximately 48 mm wide and 300 mm long, with a build thickness of approximately 96 mm.

The bar was annealed in a nitrogen atmosphere. The anneal consisted of: 1) heating the bar up to 365° C; 2) holding the temperature at approximately 365° C for approximately 2 hours; and, 3) cooling the bar to ambient temperature. The bar was vacuum impregnated with an epoxy resin solution and cured at 120° C for approximately 4.5 hours. The resulting stacked, epoxy bonded, amorphous metal bar weighed approximately 9000 g.

A trapezoidal prism was cut from the stacked, epoxy bonded amorphous metal bar with a 1.5 mm thick cutting blade. The trapezoid-shaped face of the prism had bases of 52 and 62 mm and height of 48 mm. The trapezoidal prism was 96 mm (3,800 layers) thick. The cut surfaces of the trapezoidal prism and the remaining section of the core were etched in a nitric acid/water solution and cleaned in an ammonium hydroxide/water solution.

### Example 3

#### **Preparation of Polygonal, Bulk Amorphous Metal Components**

##### **With Arc-Shaped Cross-Sections**

$\text{Fe}_{81}\text{B}_{11}\text{Si}_9$  amorphous metal ribbon, approximately 50 mm wide and 0.022 mm thick, was cut into lengths of approximately 300 mm. Approximately 3,800 layers of the cut amorphous metal ribbon were stacked to form a bar approximately 50 mm wide and 300 mm long, with a build thickness of approximately 96 mm. The bar was annealed in a nitrogen atmosphere. The anneal consisted of: 1) heating the bar up to 365°C; 2) holding the temperature at approximately 365°C for approximately 2 hours; and, 3) cooling the bar to ambient temperature. The bar was

vacuum impregnated with an epoxy resin solution and cured at 120°C for approximately 4.5 hours. The resulting stacked, epoxy bonded, amorphous metal bar weighed approximately 9200 g.

The stacked, epoxy bonded, amorphous metal bar was cut using electro-  
5 discharge machining to form a three-dimensional, arc-shaped block. The outer diameter of the block was approximately 96 mm. The inner diameter of the block was approximately 13 mm. The arc length was approximately 90°. The block thickness was approximately 96 mm.

$\text{Fe}_{81}\text{B}_{11}\text{Si}_9$  amorphous metal ribbon, approximately 20 mm wide and 0.022  
10 mm thick, was wrapped around a circular mandrel or bobbin having an outer diameter of approximately 19 mm. Approximately 1,200 wraps of amorphous metal ribbon were wound around the mandrel or bobbin producing a circular core form having an inner diameter of approximately 19 mm and an outer diameter of approximately 48 mm. The core had a build thickness of approximately 29 mm.  
15 The core was annealed in a nitrogen atmosphere. The anneal consisted of: 1) heating the bar up to 365°C; 2) holding the temperature at approximately 365°C for approximately 2 hours; and, 3) cooling the bar to ambient temperature. The core was vacuum impregnated with an epoxy resin solution and cured at 120°C for approximately 4.5 hours. The resulting wound, epoxy bonded, amorphous metal  
20 core weighed approximately 71 g.

The wound, epoxy bonded, amorphous metal core was cut using a water jet to form a semi-circular, three dimensional shaped object. The semi-circular object

had an inner diameter of approximately 19 mm, an outer diameter of approximately 48 mm, and a thickness of approximately 20 mm.

The cut surfaces of the polygonal bulk amorphous metal components were etched in a nitric acid/water solution and cleaned in an ammonium hydroxide/water  
5 solution.

Having thus described the invention in rather full detail, it will be understood that such detail need not be strictly adhered to but that various changes and modifications may suggest themselves to one skilled in the art, all falling within the scope of the present invention as defined by the subjoined claims.

CLAIMS

What is claimed is:

5 1. An electric motor having at least one bulk amorphous metal magnetic component comprising a plurality of substantially similarly shaped layers of amorphous metal strips laminated together to form a polyhedrally shaped part.

10 2. An electric motor as recited by claim 1, wherein each of said amorphous metal strips having a composition defined essentially by the formula:  $M_{70-85} Y_{5-20} Z_{0-20}$ , subscripts in atom percent, where "M" is at least one of Fe, Ni and Co, "Y" is at least one of B, C and P, and "Z" is at least one of Si, Al and Ge; with the provisos that (i) up to 10 atom percent of component "M" can be replaced with at least one of the metallic species Ti, 15 V, Cr, Mn, Cu, Zr, Nb, Mo, Ta and W, and (ii) up to 10 atom percent of components (Y + Z) can be replaced by at least one of the non-metallic species In, Sn, Sb and Pb.

20 3. An electric motor as recited by claim 2, wherein each of said strips has a composition defined essentially by the formula  $Fe_{80}B_{11}Si_9$ .

4. An electric motor as recited by claim 2, wherein said bulk amorphous metal magnetic component comprises a part of a stator of said electric motor.

5 5. An electric motor as recited by claim 2, wherein said bulk amorphous metal magnetic component comprises a stator of said electric motor.

10 6. An electric motor as recited by claim 2, wherein said bulk amorphous metal magnetic component comprises a part of a rotor of said electric motor.

15 7. An electric motor as recited by claim 2, wherein said bulk amorphous metal magnetic component comprises a rotor of said electric motor.

8. An electric motor as recited by claim 2, wherein said amorphous metal magnetic component comprises a rotor and a stator of said electric motor.

20 9. An electric motor as recited by claim 1, wherein said bulk amorphous metal magnetic component a core-loss of less than or approximately equal to 1 watt-per-kilogram of amorphous metal material

when operated at a frequency of approximately 60 Hz and a flux density of approximately 1.4T.

10. An electric motor as recited by claim 1, wherein said bulk  
5 amorphous metal magnetic component a core-loss of less than or  
approximately equal to 20 watts-per-kilogram of amorphous metal material  
when operated at a frequency of approximately 1000 Hz and a flux density of  
approximately 1.4T.

10 11. An electric motor as recited by claim 1, wherein said bulk  
amorphous metal magnetic component a core-loss of less than or  
approximately equal to 70 watts-per-kilogram of amorphous metal material  
when operated at a frequency of approximately 20,000 Hz and a flux density  
of approximately 0.30T.

15 12. In an electric motor, at least one bulk amorphous metal magnetic  
component comprising a plurality of substantially similarly shaped layers of  
amorphous metal strips laminated together to form a polyhedrally shaped  
part.

20 13. An electric motor as recited by claim 12, wherein said magnetic  
component is a stator.



15. An electric motor as recited by claim 12, wherein said magnetic component is a rotor.

5           16. An electric motor as recited by claim 12, wherein said motor comprises a member selected from the group consisting of squirrel cage motors, reluctance synchronous motors and switched reluctance motors.

10           17. An electric motor as recited by claim 13, wherein said motor comprises a member selected from the group consisting of variable reluctance motors, eddy current motors, squirrel cage motors, reluctance synchronous motors and switched reluctance motors.

15           18. An electric motor as recited by claim 14, wherein said motor comprises a member selected from the group consisting of squirrel cage motors, reluctance synchronous motors and switched reluctance motors.

Fig. 1

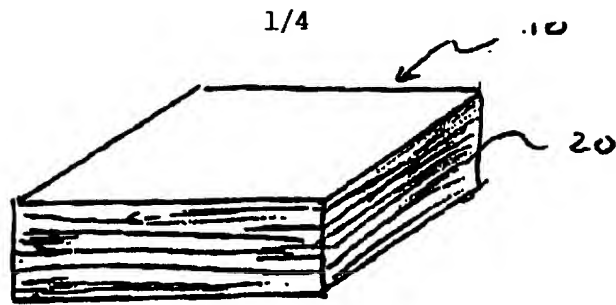


Fig. 2A

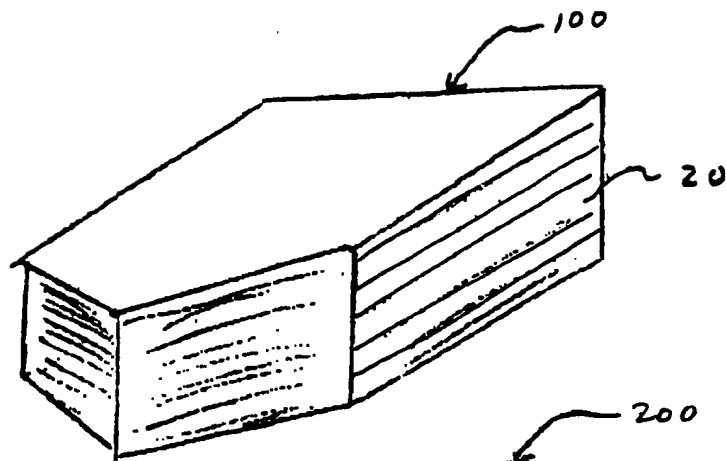


Fig. 2B

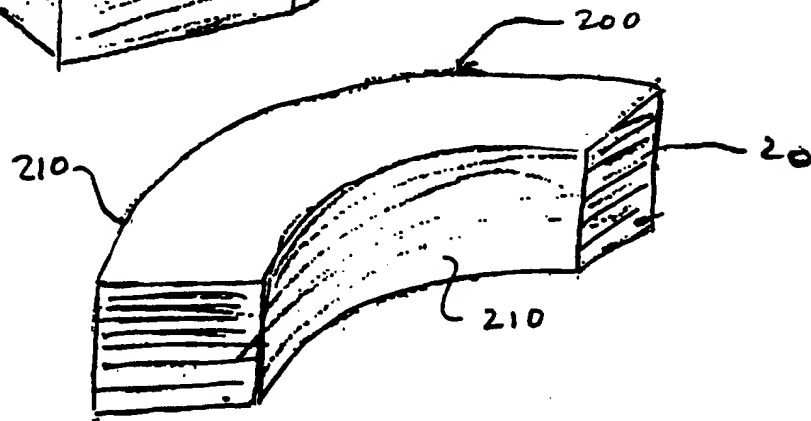


Fig. 2C

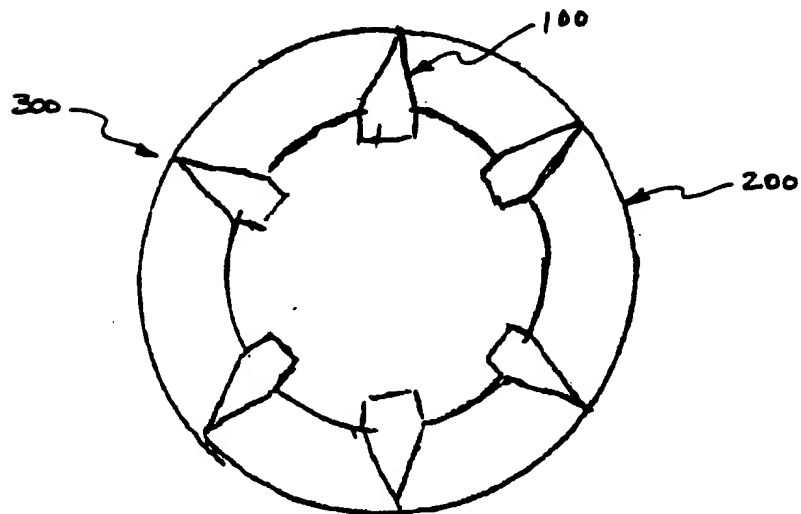


Fig. 3A

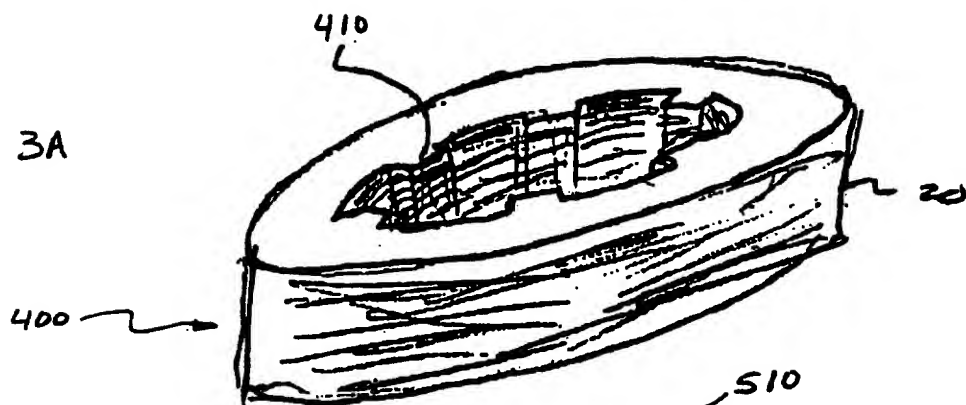


Fig. 3B

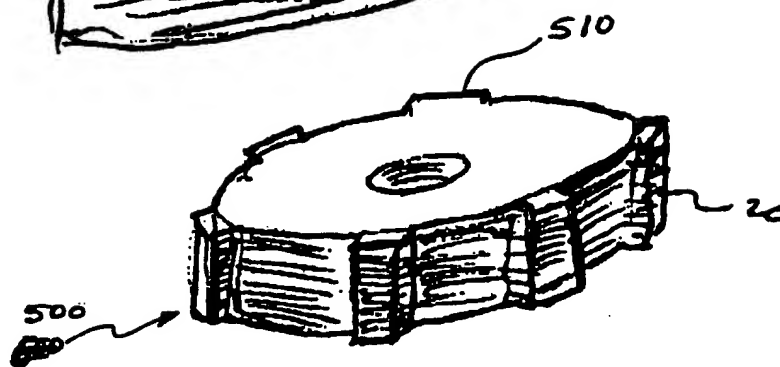
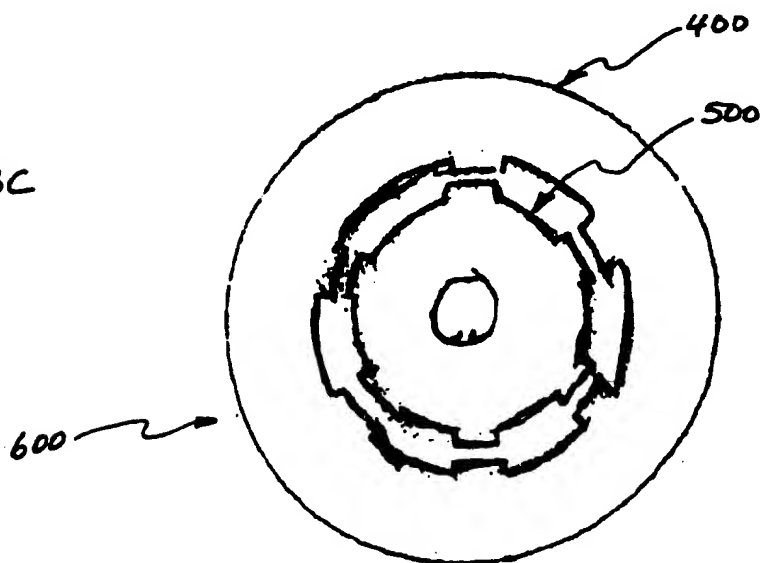


Fig. 3C



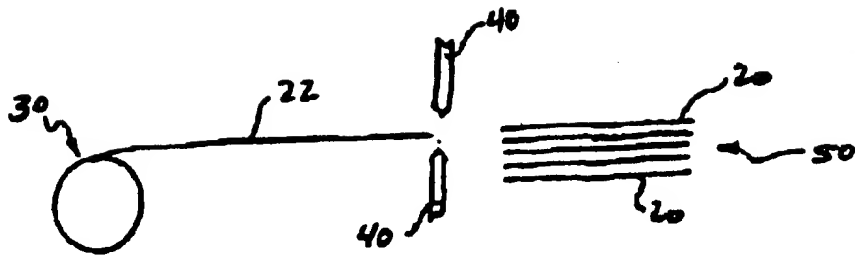


Fig. 24

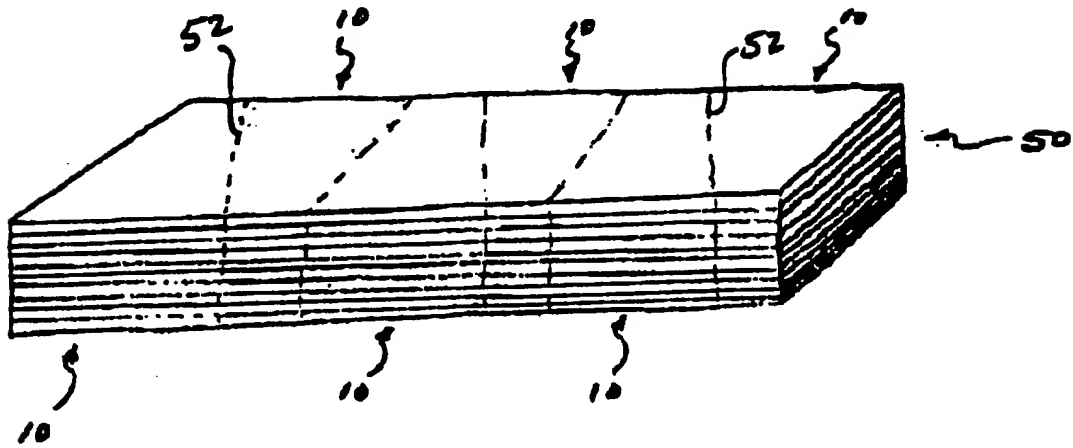


Fig. 5

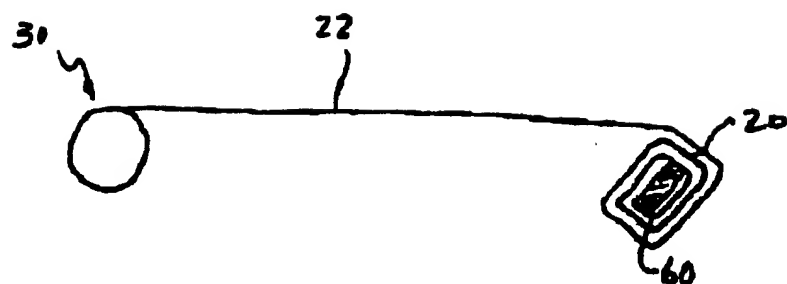


Fig. 6

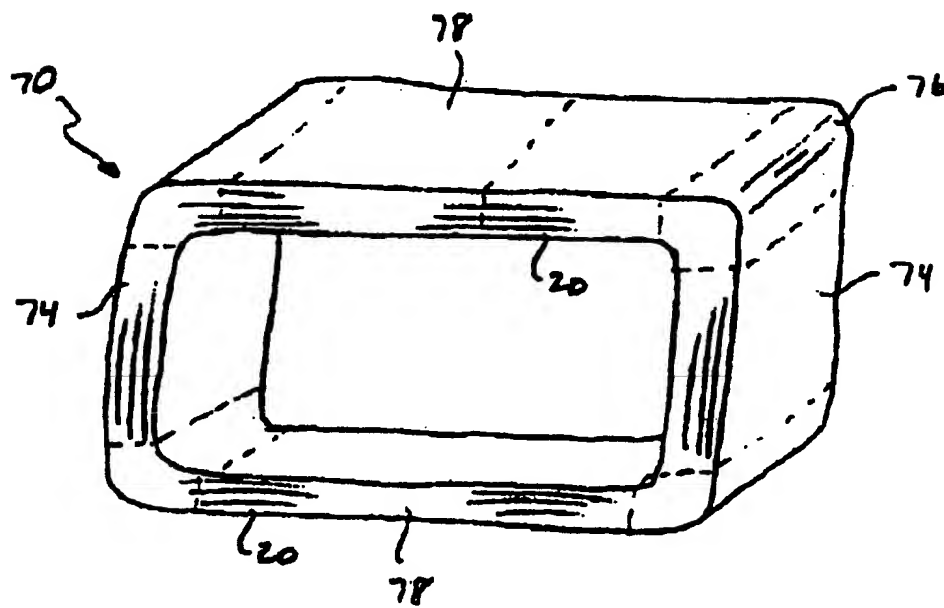


Fig. 7

Fig. 1

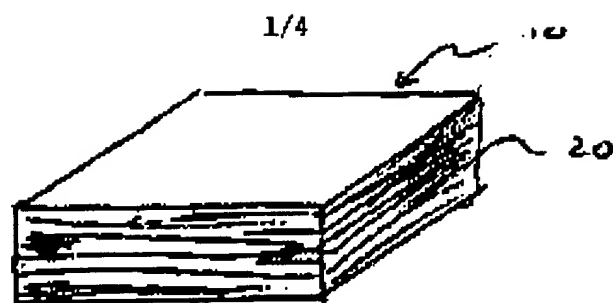


Fig. 2A

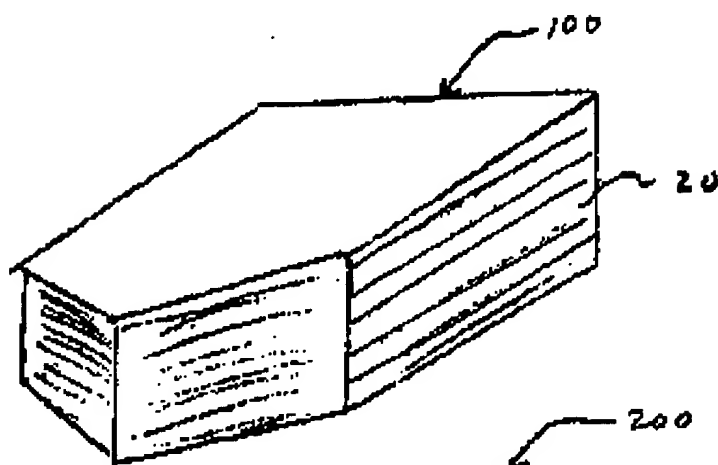


Fig. 2B

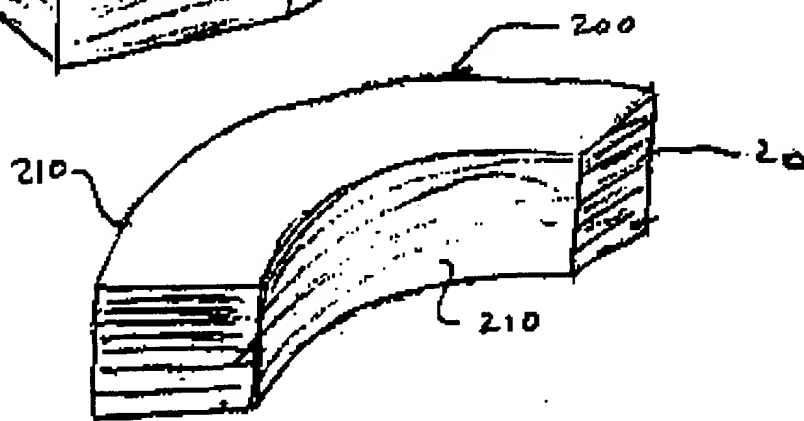


Fig. 2C

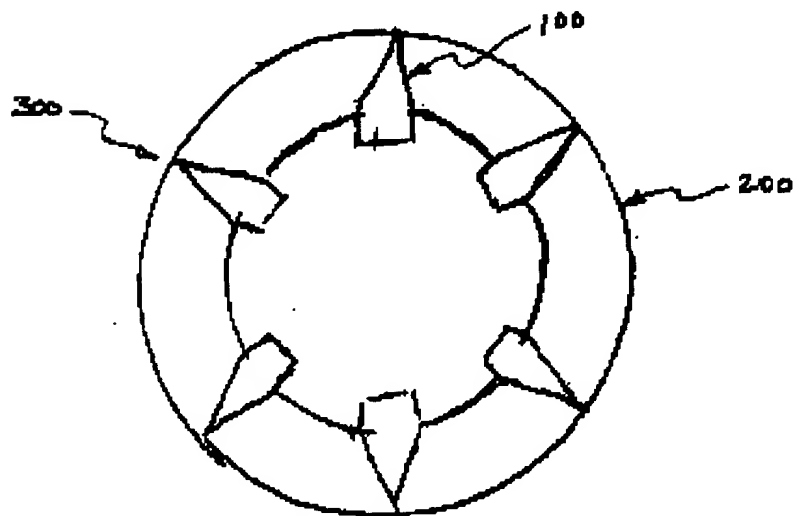


Fig. 3A

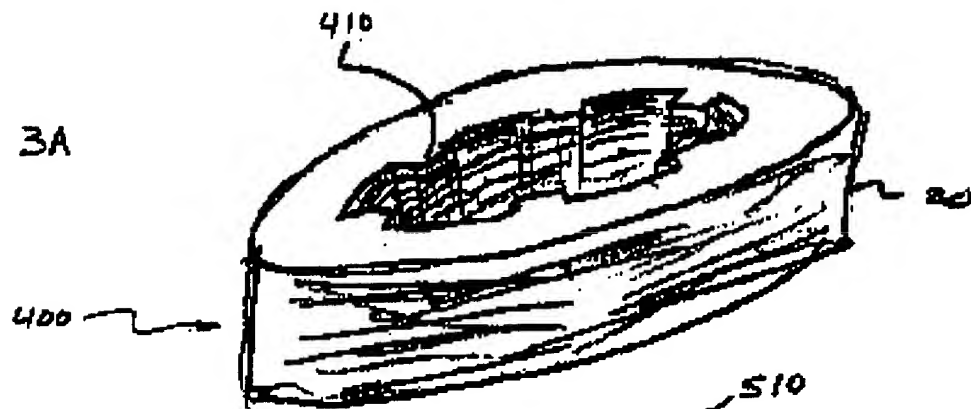


Fig. 3B

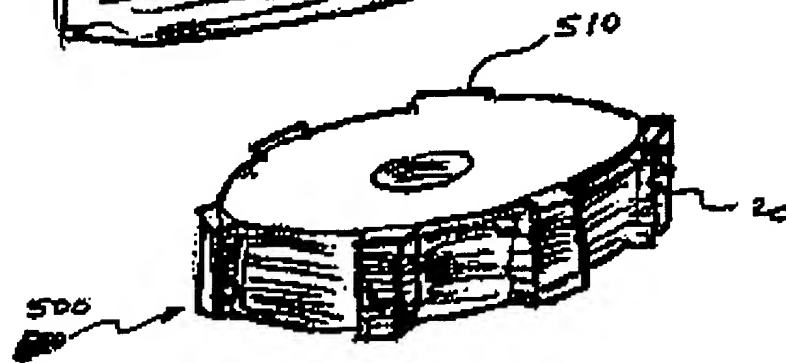
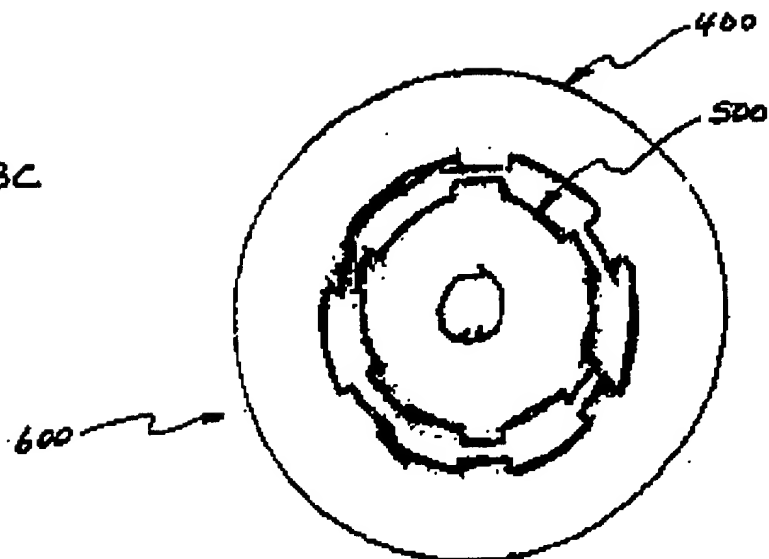
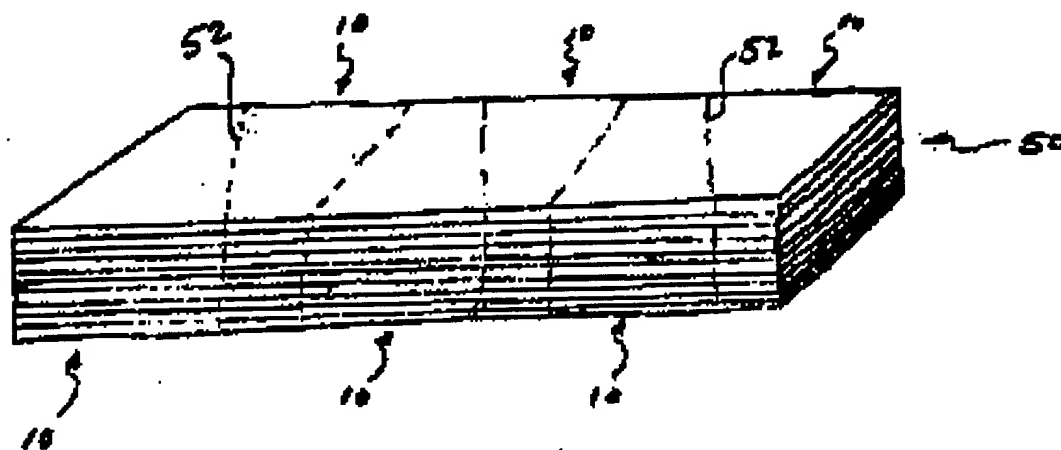
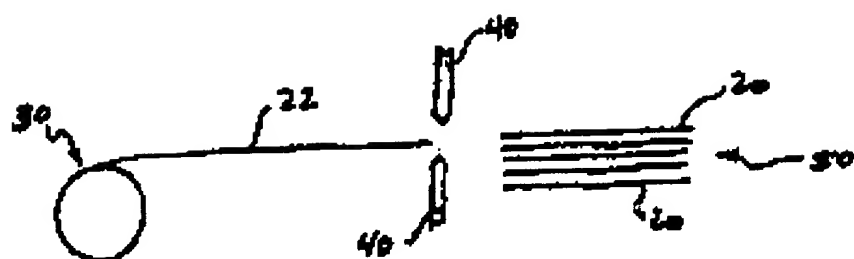


Fig. 3C







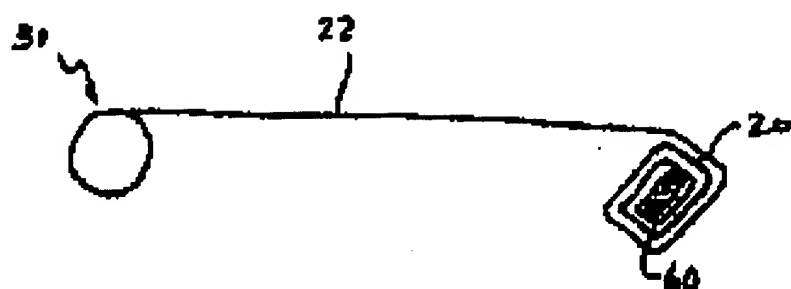


Fig. 6

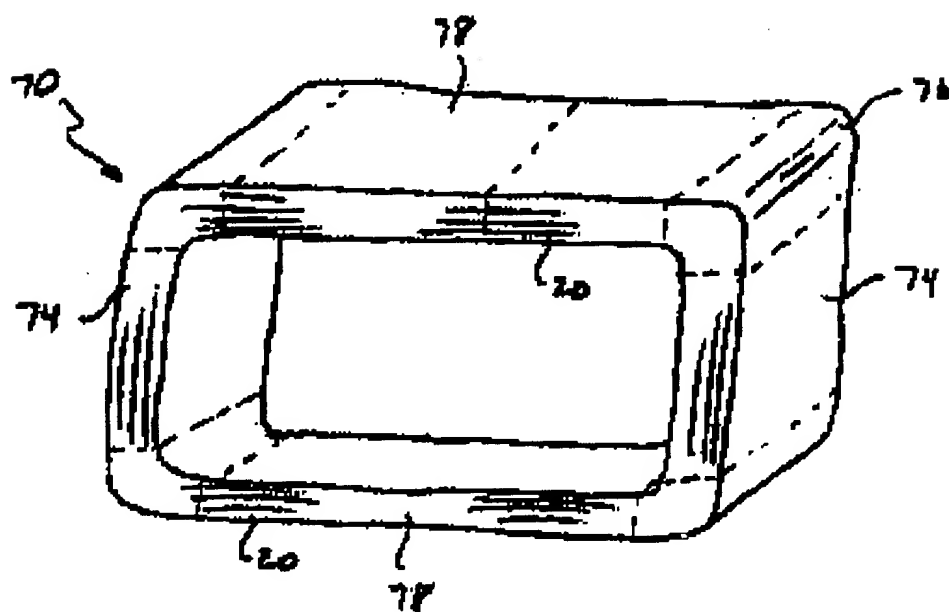


Fig. 7



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>7</sup>:</b> <b>H02K 1/02, 1/06, H01F 1/153</b>	<b>A3</b>	<b>(11) International Publication Number:</b> <b>WO 00/28640</b> <b>(43) International Publication Date:</b> 18 May 2000 (18.05.00)
<b>(21) International Application Number:</b> PCT/US99/26276 <b>(22) International Filing Date:</b> 4 November 1999 (04.11.99) <b>(30) Priority Data:</b> 09/187,656      6 November 1998 (06.11.98)      US <b>(71) Applicant:</b> ALLIEDSIGNAL INC. [US/US]; 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962-2245 (US). <b>(72) Inventors:</b> DECRISTOFARO, Nicholas, John; 33 Lincoln Avenue, Chatham, NJ 07928 (US). STAMATIS, Peter, Joseph; 107 Washington Avenue, Morristown, NJ 07960 (US). <b>(74) Agents:</b> CRISS, Roger, H. et al.; AlliedSignal Inc., Law Dept.(Olinger, A.), 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962-2245 (US).		<b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i>  <b>(88) Date of publication of the international search report:</b> 5 October 2000 (05.10.00)
<b>(54) Title:</b> BULK AMORPHOUS METAL MAGNETIC COMPONENTS FOR ELECTRIC MOTORS  <b>(57) Abstract</b>  <p>A high efficiency electric motor has a generally polyhedrally shaped bulk amorphous metal magnetic component in which a plurality of layers of amorphous metal strips are laminated together to form a generally three-dimensional part having the shape of a polyhedron. The bulk amorphous metal magnetic component may include an arcuate surface, and preferably includes two arcuate surfaces that are disposed opposite to each other. The magnetic component is operable at frequencies ranging from between approximately 60 Hz and 20,000 Hz and exhibits (i) a core-loss of less than or approximately equal to 1 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 60 Hz and at a flux density of approximately 1.4 Tesla (T); (ii) a core-loss of less than or approximately equal to 20 watts-per-kilogram of amorphous metal material when operated at a frequency of approximately 1000 Hz and at a flux density of approximately 1.4 T and (iii) a core-loss of less than or approximately equal to 70 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 20,000 Hz and at a flux density of approximately 0.30T. Performance characteristics of the bulk amorphous metal magnetic component of the present invention are significantly better when compared to silicon-steel components operated over the same frequency range.</p>		

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# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/26276

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H02K1/02 H02K1/06 H01F1/153

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H02K H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 96 00449 A (ELECTRO RESEARCH INTERNATIONAL ;RYBAK TADEUSZ (AU); GEORGOPOLOS PE) 4 January 1996 (1996-01-04)	1,2,4-8, 12,13, 15-17
Y	page 7, paragraph 2 -page 9, paragraph 5 page 12, paragraph 6 -page 14, paragraph 5; figures 1,2,4-8	3,9-11
Y	WO 98 33945 A (ALLIED SIGNAL INC) 6 August 1998 (1998-08-06) page 14, line 5 -page 15, line 11	3,9-11
X	PATENT ABSTRACTS OF JAPAN vol. 010, no. 221 (E-424), 2 August 1986 (1986-08-02) -& JP 61 058450 A (TOSHIBA CORP), 25 March 1986 (1986-03-25) abstract; figures	1,2,4-8, 12,13, 15-17

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

18 May 2000

Date of mailing of the international search report

05.06.00

Name and mailing address of the ISA

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Authorized officer

Zanichelli, F

# INTERNATIONAL SEARCH REPORT

Int'l Application No

PCT/US 99/26276

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 010, no. 221 (E-424), 2 August 1986 (1986-08-02) -& JP 61 058451 A (TOSHIBA CORP), 25 March 1986 (1986-03-25) abstract; figures ---	1,2,4-8, 12,13, 15-17
X	US 5 731 649 A (CAAMANO RAMON A) 24 March 1998 (1998-03-24)	1,12,13
A	column 16, line 11 -column 17, line 6; figure 10 ---	4
A	US 4 201 837 A (LUPINSKI JOHN H) 6 May 1980 (1980-05-06) column 3, line 40 -column 4, line 4 ---	1,12
A	PATENT ABSTRACTS OF JAPAN vol. 006, no. 251 (E-147), 10 December 1982 (1982-12-10) -& JP 57 148561 A (MATSUSHITA DENKI SANGYO KK), 13 September 1982 (1982-09-13) abstract -----	1,12

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US 99/26276

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 14, 18  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:  
Claim 14 is missing; claim 18 depends on claim 14
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box I.2

Claims Nos.: 14,18

Claim 14 is missing; claim 18 depends on claim 14

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 99/26276

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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